

# Radar and Optical Parallel Modelling of Forest Remote Sensing Data

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## Abstract

This paper describes a parallel modeling of Remote Sensing radar and optical forest data which aims at retrieving forest parameters. It describes the dual model including a forest growth model fed with biophysical parameters (biomass, leaf moisture content ...). The geometrical description is then the input of an optical model adapted to simulate hyperspectral information in the  $[0.4-2.5 \mu\text{m}]$  spectral domain, giving reflectance spectra, and a Synthetic Aperture Radar (SAR) model, giving the polarimetric and interferometric observables. As an illustration, the first results obtained by both models outputs are presented.

## Keywords

*Remote Sensing; Radar Simulation; Hyperspectral Simulation; Radar Polarimetry; Forest Electromagnetic Scattering; Biomass; Forest Height Estimation; Moisture Content Estimation*

## Introduction

Retrieval of bio-physical parameters of forests with remote sensing is nowadays a challenge. In particular, the biomass of the canopy, soil and branches moisture contents are three parameters of interest. It is well known that low frequency radars may furnish lots of characteristics of forests, and in particular P band is often proposed [1], [2] for biomass estimation. On the other hand, spectral signatures provided by optical measurements can provide features of forest vegetation, like Leaf Area Index (LAI) [3] and Normalized Difference Vegetation Index (NDVI) and even tree species [4].

Hopefully, using both sources of information through a combination process should improve the determination of the forest characteristic parameters. To evaluate the potential of this combined approach, a focus is done in this paper on a parallel direct modelling approach in which the same forest scenario is simulated in polarimetric P band backscattering and

in optical narrow bands corresponding to  $[0.4-2.5 \mu\text{m}]$ .

In section II the general functioning of the parallel modelling, with the links between the models, is described. Then, in section III a sensitivity study is carried out with the radar model only on a forest with different biomass, soil moisture content and branches moisture content will be presented. Finally, section IV consists in a sensitivity study with the optical model.

## Parallel Modelling Description

### Common Forest Characterization (growth model)

The characterization of the forest is the same for both models. The term parallel modelling is then introduced. In fact, a ground representation of a maritime pine forest as a function of growing age and consequently growing biomass is obtained thanks to a growth model depicted in [5], which delivers leaves LAI and the statistical parameters of the trunks and branches in terms of size, location and orientation, for a given biomass.

The ground is made of a bare and flat soil. Moisture contents for the soil, branches and trunks are inputs of the model.

The biomass in this work is defined as the sum of branches and trunks biomass. The leaf biomass is considered as negligible.

### Radar and Optical Model Description

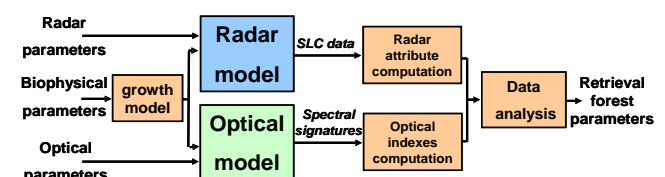


FIG. 1 GENERAL DIAGRAM OF THE PARALLEL RADAR AND OPTICAL MODEL

As shown in Fig.1, this geometrical information is then used for MIPERS (Multistatic Interferometric Polarimetric Electromagnetic Model for Remote Sensing) simulations of the radar backscattering matrix [6], and for DART (Discrete Anisotropic Radiative Transfer) simulations of the scene spectral reflectance and 3D radiative budget [7]. The optical model uses a discrete ordinate ray tracing method for simulating the scene Bottom of Atmosphere (BOA) spectral reflectance.

### Geometric input model Adaptations

The two geometric models are based on different principles. For the radar model MIPERS, the scatterers are represented by cylinders for the trunks and branches, as shown in Fig. 2.

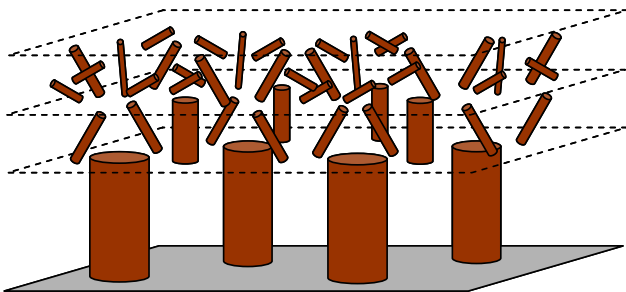


FIG. 2 SCATTERER REPRESENTATION FOR THE RADAR MODEL

At P-Band, the wavelength is 75cm so the leaves have no any influence and so are not considered in the simulation. For each pixel of the Single Look Complex (SLC) data simulated, the coherent sum of the bare soil and the cylinders backscattering is computed.

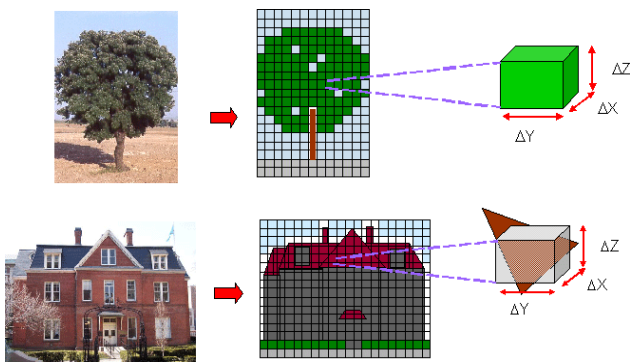


FIG. 3 REPRESENTATION OF VOLUME (UP) AND SURFACES (DOWN) IN THE OPTICAL MODEL

For the optical model DART, as shown in Fig. 3, two types of elements are considered: volume (for leaf) and surface (for trunks, branches and ground) elements.

In order to have a radar and optical scene geometric representation as close as possible, the cylinders of the radar model are replaced by 3D elements made of

polygons. Leaves are represented by volumes with a Leaf Area Index (LAI) given by the growth model. The LAI is a function of age.

### Radar and Optical Ground Parameter Simulations

Radar simulations are carried out on an 80 by 80 m wide scene, with a resolution of 1 m, at P band (430 MHz).

The complex backscattering field is then computed for all the pixels associated with the branches, trunks and soil. An average value on the whole scene is then obtained for all polarizations.

The leaf moisture content in optical simulations is linked to the branch moisture content in radar simulations. For soils, the moisture content is independent on leaf or branches moisture content.

Optical simulations are performed with the following parameters:

- Pine leaf spectral signature is provided by the ASTER database [8] for undergrowth. LAI is decreasing with biomass from 5.38 m<sup>2</sup>/m<sup>2</sup> to 2.45 m<sup>2</sup>/m<sup>2</sup>;
- PROSPECT [9] model is coupled with DART to simulate the impact of pine leaf moisture content on the global scene spectral signature.
- Spectral signatures for trunk and branch have been measured on pine bark in 2002 [10];
- The following hypothesis is done: a bare soil corresponds to a null biomass (0 ton/ha).
- The soil spectral signature is extracted from the database at the ONERA including spectral signatures, measured in laboratory, of bare soils according to soil moisture content [11];
- The scene is 12m by 12m wide, with a spatial resolution of 4m. Simulations are lead for 160 spectral bands of the reflective spectral domain (0.4 – 2.5 μm). These parameters are chosen according to airborne campaigns preformed by the ONERA [12].

For every pixel, and every spectral band, the bottom of atmosphere reflectance is computed.

Then, four optical indexes are deduced:

- The Normalized Difference Vegetation Index (NDVI), linked to the LAI ;

- The Cellulose Absorption Index (CAI), which is sensitive to dead branches and trunks in the scene ;
- The Global Vegetation Moisture Index (GVMI), linked to the leaves moisture content ;
- The Normalized Index of SWIR domain for soil m.c. estimation from Linear correlation (NINSOL), a bare soil index, is sensitive to soil moisture content.

### Radar Simulations

Fig. 4 represents the evolution of polarimetric backscattering as a function of biomass for various soil moisture contents and Fig. 5 represents the evolution of polarimetric backscattering as a function of biomass and branches moisture content.

Soil moisture content varies between a few per cents for very dry soils to more than 50% for very wet, saturated soils, with average values for forests around 20%.

In Fig. 4, the average values of biomass are kept for vegetation, and only soil moisture content is parameterized. Actually, soil moisture content is supposed to vary independently of vegetation moisture content. It can be seen that this parameter poorly influences HV, has a strong influence on VV for low ages, a reduced one at higher ages and is overall prominent for HH.

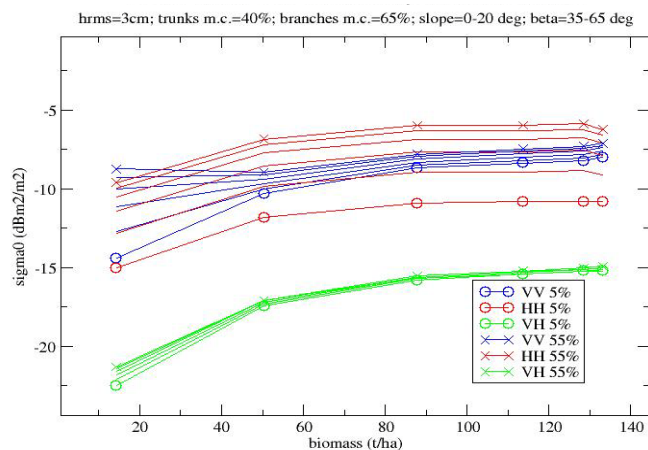


FIG. 4 GENERAL DIAGRAM OF THE PARALLEL RADAR AND OPTICAL MODEL

Actually, HH intensity follows the same evolution with different offsets. For usual values of moisture content, around 25%, the impact is low. We can notice that HV intensity is poorly influenced by soil characteristics, which is expected.

For branch moisture content, according to literature [14], it looks reasonable to consider a variation between a ceiling value of 40% and a top value of 70%.

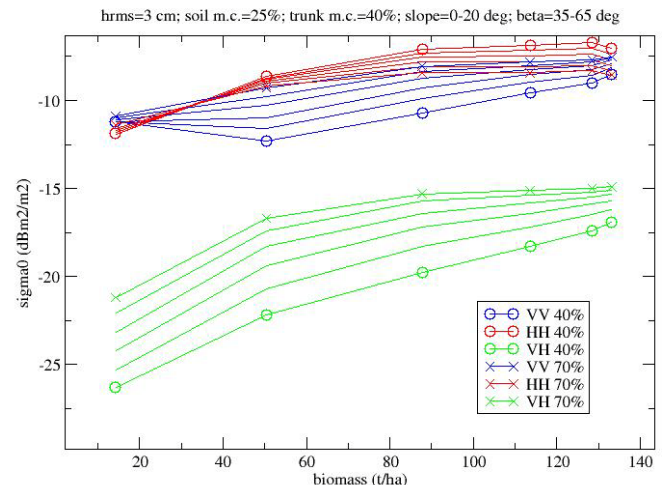


FIG. 5 GENERAL DIAGRAM OF THE PARALLEL RADAR AND OPTICAL MODEL

In this case, Fig. 5 shows a very strong influence of this parameter on the polarimetric response in P band for all polarizations. Actually, as branch moisture content increases, VV and HV increase but also canopy extinction increases which makes decrease the trunk double bounce with soil which mainly corresponds to HH.

It can be seen that the influence of the input parameters on the output ones is complex, and that incorporating in the analysis additional data may be fruitful.

### Optical Simulations

#### Parameters Validation and Optimization

In order to analyse the impact of some parameters (like the cells resolution, the cylinders number of polygons, and the threshold on minimum branches radius) introduced in the optical simulations which have a strong influence on the computing time, sensitivity study is performed.

To begin with, five identical simulations were performed with various cells side dimensions, from 50 cm to 4 m.

Fig. 6 shows the variation of reflectance spectra in Near Infra Red, between 0.8 and 1.3  $\mu$ m, for cells side dimensions higher than 1 m. A resolution of 0.5 m is then chosen in order to have a sufficient margin.

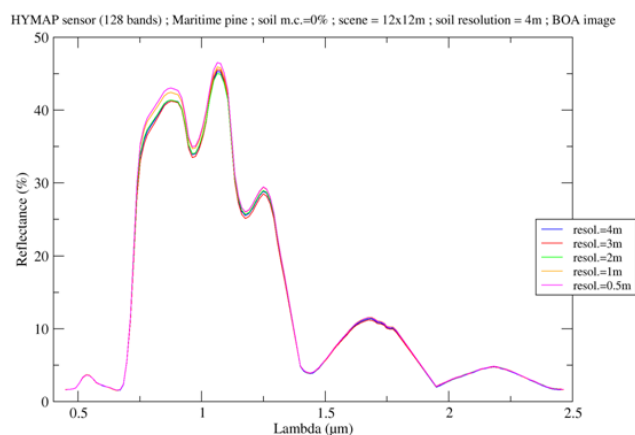


FIG. 6 REFLECTANCE SPECTRA ON A FOREST WITHOUT LEAVES, FOR CELLS RESOLUTIONS FROM 0.5 CM TO 4 M

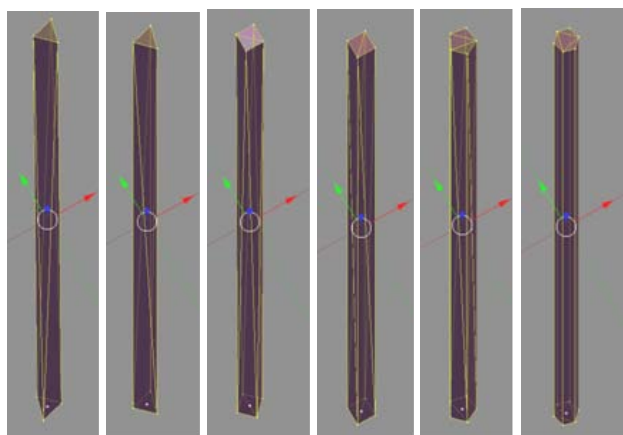


FIG. 7 3D REPRESENTATIONS OF CYLINDERS WITH, FROM LEFT TO RIGHT, 8 POLYGONS AND A GEOMETRICAL VERTICAL ASYMMETRY, 8 POLYGONS AND SYMMETRY, 12 POLYGONS AND ASYMMETRY, 12 POLYGONS AND SYMMETRY, 16 POLYGONS AND ASYMMETRY, 20 POLYGONS AND SYMMETRY

As previously explain, the perfect cylinders of the radar simulation are represented in the optical simulation by 3D objects made of polygons (c.f. II.C.). Six simulations are performed using a different 3D object, as given in Fig. 7, to represent cylinders.

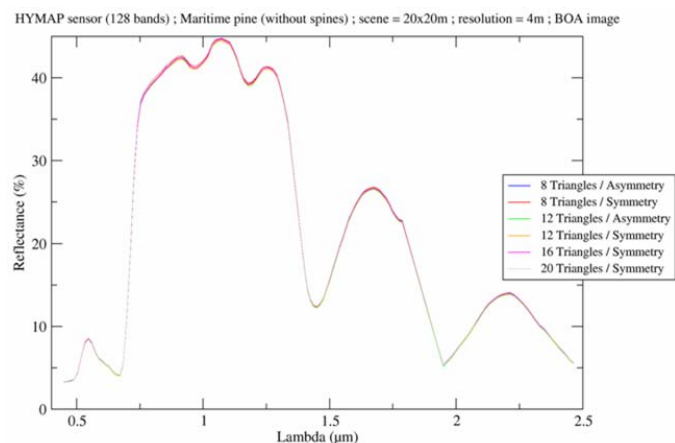


FIG. 8 IMPACT OF 3D REPRESENTATION OF BRANCHES ON REFLECTANCE SPECTRA

One can see in Fig. 8 that 3D representation of cylinders has no influence on reflectance spectra. As a consequence, the simplest object with 8 asymmetrical cylinders is retained.

Finally, simulations are performed to see if it is possible to keep only the branches with radius higher than 2 cm, or those with radius higher than 4cm.

In front of the considerable differences in the reflectance spectra obtained in Fig. 9, it is decided to keep all the branches that are involved in the radar modelling.

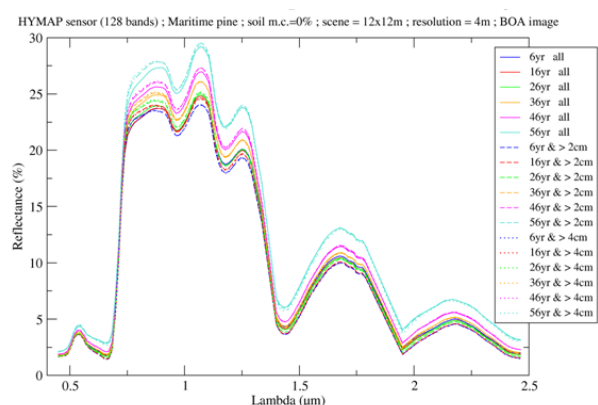


FIG. 9 REFLECTANCE SPECTRA FOR ALL BIOMASSES AND ALL BRANCHES (SOLID LINES), BRANCHES WITH RADIUS HIGHER THAN 2 CM (DASHED LINES) AND BRANCHES WITH RADIUS HIGHER TAN 4 CM (DOTTED LINES)

### Optical Simulations for Forests

Here leaves, needles as a matter of fact, are considered. For the first simulation, several soil spectral signatures of the same kind of soil, with moisture content values from 0 % for a dry soil, to 39 % for a wet soil, are retained. The biomass varies the same way as those for radar simulations. The optical indexes have been computed for the previous parameters and shown in Fig. 10.

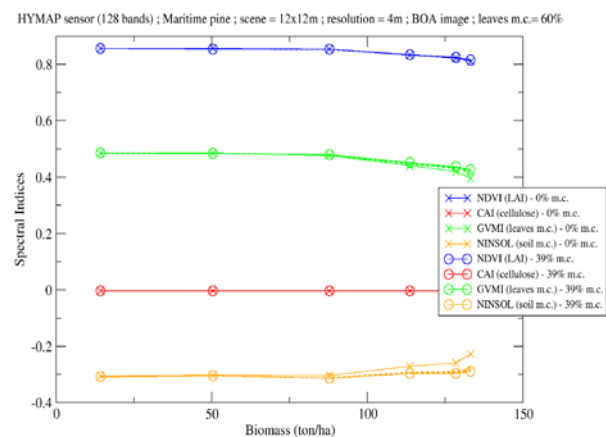


FIG. 10 SENSITIVITY OF SPECTRAL INDICES FOR SEVERAL BIOMASS AND SOIL MOISTURE CONTENT.



One can notice that the NDVI is a little bit sensitive to the biomass variation and independent of the soil moisture content parameter. In fact, when the biomass is increasing, the LAI is decreasing, because as each tree biomass is growing, their density is decreasing, so the part of the soil in the pixel is increasing.

For same reason, the NINSOL is more sensitive to soil moisture content for high biomass.

For the second simulation, several leaf moisture content values are simulated with PROSPECT, from 39 % to 92 %, and the corresponding spectral signatures are used as input of the optical model. The biomass varies the same way as previously. The result is shown in Fig. 11.

The NDVI is not sensitive to leaf moisture content and evolves the same way as in Fig. 10. The NDVI is then not sensitive to branch moisture content variation.

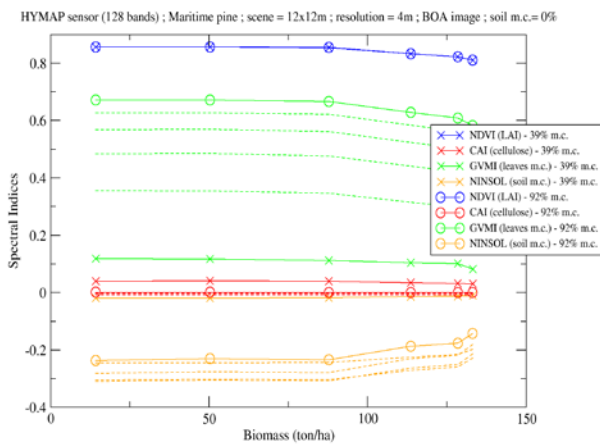


FIG. 11 SENSITIVITY OF SPECTRAL INDICES FOR SEVERAL BIOMASS AND LEAVES MOISTURE CONTENT

For the GVM, strong variations can be seen in the figure. The GVM is much more significantly linked to leaf moisture content, than to biomass.

The NINSOL presents the same evolution with biomass and leaf moisture content. This index is specified for bare soil and the modelling scene represents forest.

## Conclusion

A parallel model for simulating electromagnetic scattering and optical reflectance spectrum of forests has been presented. It starts from a growth model, and the subsequent geometrical discrete description is the common input for both optical and radar models. Simulations parameters have been validated, and a sensitivity analysis has been carried out on both simulation models. This sensitivity analysis has

exhibited the benefit which may be withdrawn from the use of both models separately.

The setup of parallel radar and optical model and the analysis of its first results show the perspective of such a model in the combination of radar and optical data.

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Since then, he has been working as a research engineer in the microwaves department. In 1990-91, he spent a sabbatical year at New York University, Farmingdale, NY. In 1997, he obtained the university diploma of Habilitation to Direct Research. He has worked in the fields of radiation and scattering of antennas, microwave devices, radar targets imaging, frequency selective surfaces, ultra wide band scattering, subsurface targets, electromagnetic modeling, natural targets scattering and remote sensing. His current interests include electromagnetic modeling for radar remote sensing and proximity scattering experiments.



**Sophie Fabre**, research engineer, received the post graduate in Signal and Image Processing (UPS, Toulouse III, and France) in 1996 and the doctorate of signal, image and communication (ISAE, Toulouse, France) in 1999 on multi-sensor fusion.

She worked during five year on projects FARMSTAR (precision crop management) and GEOLAND (European project on the vegetation characterization using multi-temporal MERIS data) on behalf of ASTRIUM (France). Then, she joined THALES Services (France) during one year to support the specification of the PLEIADES radiometric correction module. Finally, she joined the department DOTA (Theoretical and Applied Optics Department) part of Onera since 2006 in order to work on hyperspectral data processing. She is providing since 2007 the project STAD, ground segment of the Sysiphe system (airborne hyperspectral instruments covering the spectral domain [0.4-12  $\mu$ m] at a spatial resolution of 0.5 m) for DGA (France). Its recent works first concern the geometric correction, the inter-instrument registration in the STAD frame and on the other hand the estimation of physical parameters (soil moisture content ...) owing to hyperspectral data processing.